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Search for the Chiral Magnetic Effect from STAR Beam Energy Scan-II data

Zhiwan Xu (zhiwan.xu@anl.gov) for the STAR Collaboration **Argonne National Laboratory**

Abstract

The Chiral Magnetic Effect (CME) manifestly violates local P and CP symmetry, and it describes the induction of an electric charge separation along \mathring{B} direction. In this work, we measure a correlation observable $\Delta \gamma^{112}$ between two charged mesons and event plane to detect the charge separation. The data were taken from Au+Au collisions during the RHIC Beam Energy Scan phase II and at the top RHIC energy. To mitigate the background induced by elliptic flow, we adopt a novel event shape selection (ESS) approach that classifies events based on their shape and determines $\Delta \gamma^{112}$ at the zero-flow limit, which we denote as $\Delta \gamma_{\rm ESS}^{112}$. The value of $\Delta \gamma_{\rm ESS}^{112}$ is reduced from the inclusive $\Delta \gamma^{112}$ by more than five-fold. The measured $\Delta \gamma_{\rm ESS}^{112}$ value in the 20%–50% centrality range is positive finite with a 3σ significance at each of the center-of-mass energies $\sqrt{s_{NN}}$ =11.5, 14.6, and 19.6 GeV.

Chiral Magnetic Effect (CME)

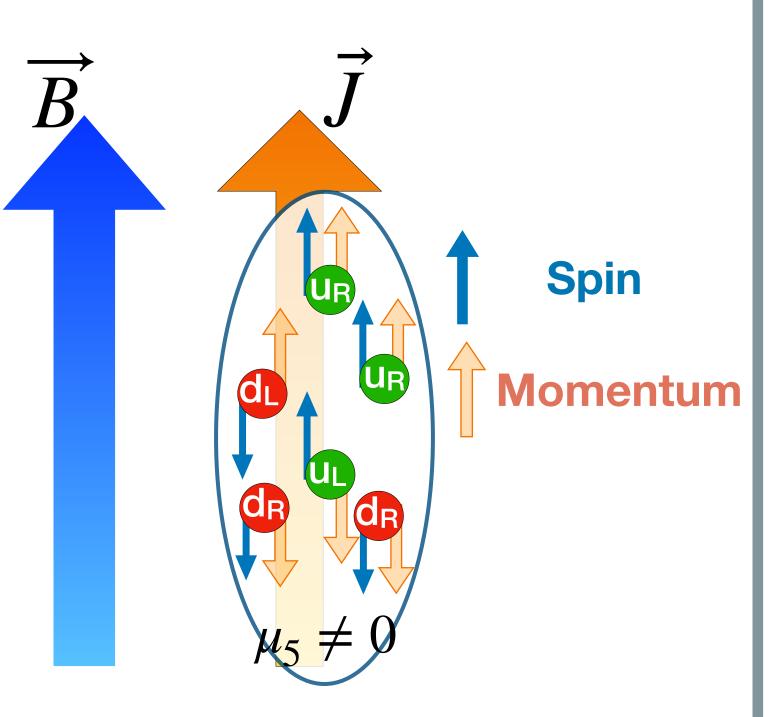
Magnetic field (B) can induce charge separation (current J) for quarks at chirality imbalance ($\mu_5 \neq 0$).

Manifestly violate local P $J \propto \mu_5 B$ and CP symmetry.

odd parity even parity

3 conditions of CME:

- Chiral Symmetry Restoration
- Topological Vacuum Transition
- A strong B field



S.A. Voloshin, Phys. Rev. C,70, 057901 (2004)

CME Observable in Heavy Ion Collisions

$$\frac{dN_{\pm}}{d\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos(n\phi - n\Psi_{\text{RP}}) + 2a_1^{\pm} \sin(\phi - \Psi_{\text{RP}}) + \dots$$

We focus on: $\gamma^{112} = \langle \cos(\phi_1 + \phi_2 - 2\psi_{RP}) \rangle = \langle v_1 v_1 \rangle - \langle a_1 a_1 \rangle + BG(v_2^{cl})$

CME signal: $\Delta \gamma^{\text{CME}} = \gamma^{\text{OS}} - \gamma^{\text{SS}} > 0$

BKG indicator: $\gamma^{132} = \langle \cos(\varphi_1 - 3\varphi_2 + 2\Psi_{RP}) \rangle \rightarrow \Delta \gamma^{132}$

Event Shape Selection (ESS):

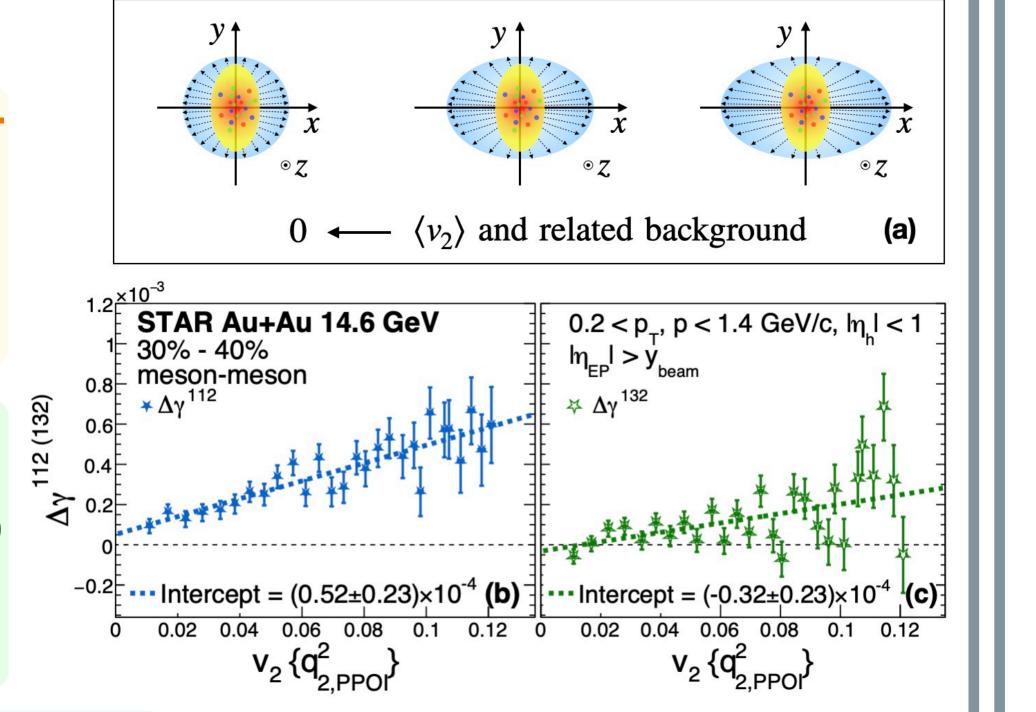
1. Categorize events with eventshape variable

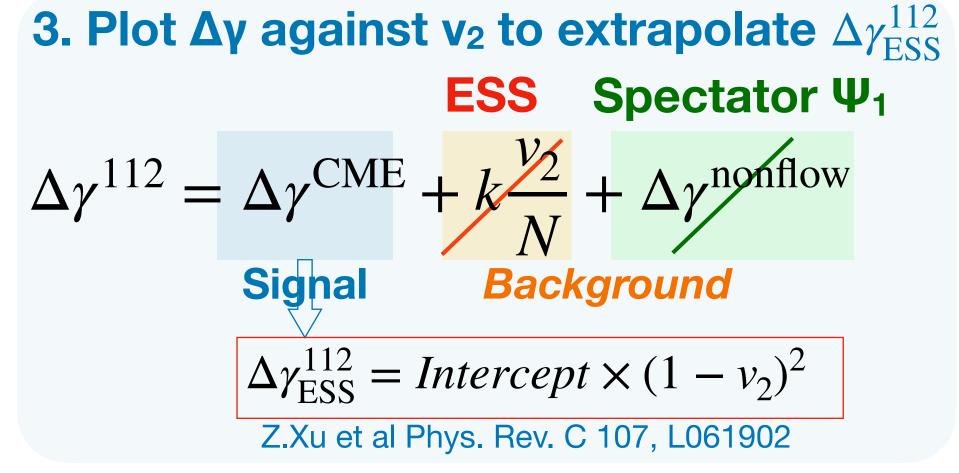
$$q_2^2 = \frac{\left(\sum_{i=1}^N \sin 2\varphi_i\right)^2 + \left(\sum_{i=1}^N \cos 2\varphi_i\right)^2}{N(1 + N\langle v_2\rangle)}$$
Z. Xu et al, PLB 848(2024)138367

2. Measure the $\Delta y \& v_2$

Optimal Solution of ESS pair q₂ (PPOI) single v₂ (POI)

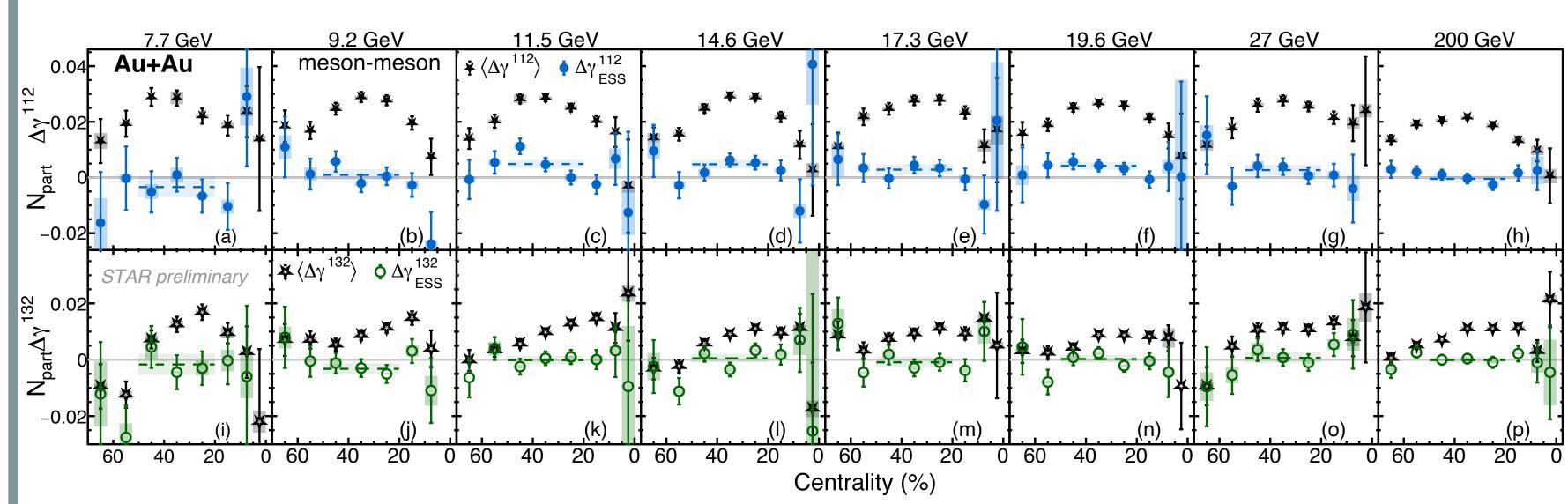
 Adding momenta of pair POI (PPOI) to mimic resonance decay.





- Nonflow background removal: spectator Ψ₁
 - Short range nonflow: large eta gap between TPC POI and spectators.
 - Momentum conservation: using spectators from west and east sides.
- Flow background removal: The ESS technique extrapolates an observable to isotropic emission, characterized by zero elliptic flow (v₂).

Beam Energy Scan-II results

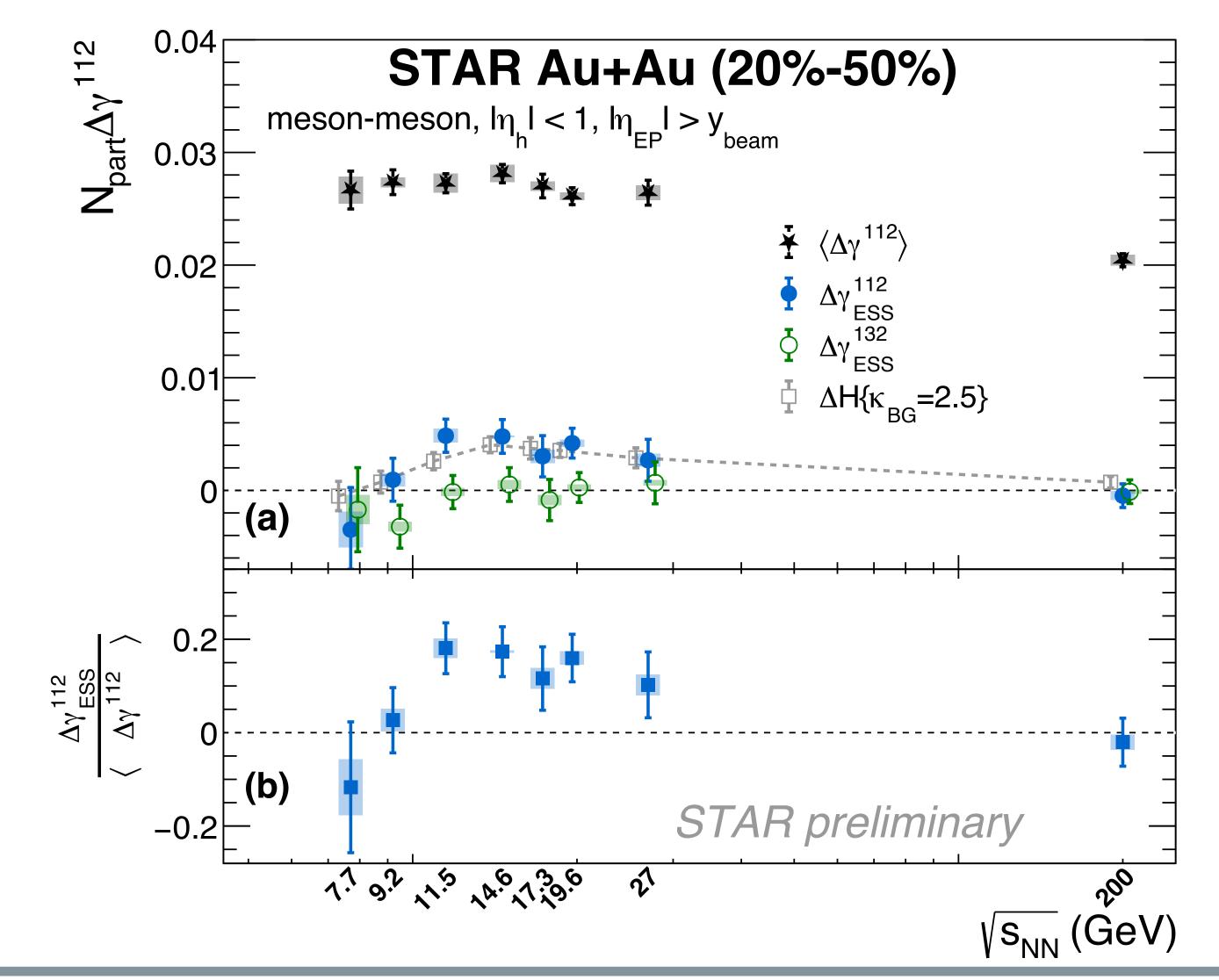


- \circ $\Delta \gamma_{\rm ESS}^{132}$ is consistent with zero at all energies effectiveness of background suppression with ESS and the usage of spectator plane.
- The ESS method identifies that at least 80% of $\langle \Delta \gamma^{112} \rangle$ is from the flow-related background.
- Rise and fall trend in energy dependence: residual charge separation is over 5σ significance when combining 10-20 GeV, assuming similar physics conditions.
- At 200 GeV, result is well consistent with zero, aligned with the finding in Isobar blind analysis.

	•
7.7	Consistent with 0
9.2	Consistent with 0
11.5	3σ
14.6	3.1σ
17.3	1.6σ
19.6	3.5σ
27	1.3σ
200	Consistent with 0

Significance

√s_{NN} (GeV)



Summary

- Search for the CME in heavy-ion collision probes the intrinsic properties of QCD.
- STAR latest CME searches use a novel Event Shape Selection method to suppress flow-related backgrounds. A rise-fall energy trend is observed.
 - Below √s_{NN} = 10 GeV and at 200 GeV, the charge separation is consistent with zero: Chiral symmetry not fully restored below 10 GeV? B field decaying fast?
 - \circ At each collision energy of 11.5, 14.6 and 19.6 GeV, a positively finite $\Delta \gamma_{\rm FSS}^{112}$ is observed at mid-centrality where we expect a magnetic field.

Acknowledgements

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